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Application of Life Cycle Assessment for the Environmental Certificate of the Mercedes-Benz S-Class

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Abstract

Background, Aims and Scope. Life cycle assessment (LCA) is used as a tool for design for environment (DfE) to improve the environmental performance of the Mercedes Car Group products. For the new S-Class model a brochure including an environmental certificate and comprehensive data for the product was published for the first time. The paper explains the use of LCA for these applications and presents exemplary results.

Methods. The environmental certificate brochure reports on processes, data and results based on the international standards for life cycle assessment (ISO 14040, ISO 14041, ISO 14042, ISO 14043), for environmental labels and declarations (ISO 14020, ISO 14021) and for the integration of environmental aspects into product design and development (ISO 14062), which are accepted by all stakeholders.

Results and Discussion. The compliance with these international standards and the correctness of the information contained in the certificate were reviewed and certified by independent experts. The global warming potential (GWP 100 years) of the new S-Class vehicle was reduced by 6%, the acidification potential by 2%, the eutrophication potential by 13% and the photochemical ozone creation potential by 9%. In addition, the use of parts made from renewable materials was increased by 73 percent to a total of 27 parts with a weight of about 43 kilograms. A total of 45 parts with a weight of 21.2 kilograms can be manufactured using a percentage of recycled plastics.

Conclusion. The application of LCA for DfE is fully integrated as a standard function in the vehicle development process. The DfE/LCA approach at the Mercedes Car Group was successful in improving the environmental performance of the new S-Class. It is shown that the objective of improving the environmental performance of the new S-Class model, compared to the previous one, was achieved.

Recommendation and Outlook. Vehicles are complex products with very complex interactions with the environment. Therefore, simple solutions, e.g. pure focus on fuel economy or light weighting or recycling or single material strategies, are bound to fail. It is a main task of DfE and LCA to take this fact into account and come up with more intelligent solutions. The application of LCAs for DfE and their integration as standard practice in the product development process is both the most demanding and the most rewarding. It requires a substantial effort to acquire the know-how, the data, the experience and the tools needed to generate meaningful results just in time. However, this is the way how LCA and DfE can add value – they have to be 'built' into the product.

Keywords: Automotive industry; cars; design for environment; DfE; environmental certificate; ISO-standards; life cycle assessment; LCA, vehicle

Introduction

Environmental protection is one of the fundamental corporate objectives of the DaimlerChrysler Group. It is not one isolated goal among others, but is an integral component of a business strategy geared to long-term value enhancement. Design for Environment (DfE) is one of the key elements to reach this target. A general outline of integrating environmental aspects into product design and development based on ISO TR 14062 is given e.g. by Quella (2003). The DfE-process at the Mercedes Car Group takes the entire product lifecycle into account, from design through production and use, to recycling and disposal. Therefore, life cycle assessment (LCA) for components and entire vehicles is used as an important tool for DfE.

This paper explains the use of LCA and DfE during the development of the Mercedes-Benz S-Class vehicle and shows exemplary results. A full documentation is available in a 44 page brochure called 'Environmental Certificate Mercedes-Benz S-Class' that can be obtained from the corresponding author (Mercedes-Benz 2005) or downloaded from the DaimlerChrysler website (DaimlerChrysler 2005).

Embodied in DaimlerChrysler's environmental protection guidelines is the principle that we develop products which in their respective market segments are highly environmentally responsible, and that we inform the public in a comprehensive way about environmental protection affairs. The brochure and environmental certificate, developed for the first time for the new S-Class, is a further example of how these guidelines are put into practice. It is aimed at customers and shareholders as well as interested parties inside and outside the company. The preparation was guided by the international standards for life cycle assessment (ISO 14040, ISO 14041, ISO 14042, ISO 14043), for environmental labels and declarations (ISO 14020; ISO 14021) and for the integration of environmental aspects into product design and development (ISO 14062), which are accepted by all stakeholders. The compliance with these standards and the correctness of the information contained in the certificate were reviewed and certified by independent experts of TÜV Süd Management Service GmbH (TÜV 2005).

1 DfE-Process

Reducing the burden on the environment caused by emissions and resource consumption over the entire lifecycle is

vital to improving the environmental compatibility of a vehicle. The ecological burden caused by a product is largely determined in the early development phase (Saur et al. 1997). Later corrections to product design can only be effected at high expense. The sooner design for environment is integrated into the development process, the greater the benefit will be in terms of minimizing environmental load and cost (Finkbeiner et al. 2000). This means 'building' environmental protection into the products from the very beginning. Ensuring this is the task of DfE. The goal is objective and measurable improvement of environmental compatibility and, simultaneously, compliance with the demands of more and more customers who consider environmental aspects like the reduction of fuel consumption and emissions or the use of environmentally acceptable materials.

The DfE concept at Mercedes-Benz implements a procedure based on Simultaneous Engineering comprising three main elements (Ruhland et al. 2004):

1. A methodological procedure which allows integration of environmental targets and measures into the Mercedes-Benz Product Development System. This procedure defines interfaces with development phases and is used as a formalized PDCA cycle (Plan, Do, Check, Act).
2. Tools and Databases to assist the DfE procedure in simulating and evaluating the environmental performance of future vehicles or parts.
3. An organizational structure that formalizes the integration of DfE into the development process

Tools and databases are continuously developed, maintained and optimized. Examples are tools for product modeling, recycling and dismantling modeling/planning, database for restricted substances, material database and LCA software and database. To handle all the relevant information, tools and databases to assist the DfE procedure in simulating and evaluating the environmental and recycling performance of future vehicles or parts are indispensable. To make DfE more efficient and less time, respectively resource, consuming, a lot of research for new LCA methods has been done. However a recycling and dismantling assessment which is closer linked to the product structure of the car has yet not been an integrated part of this LCA software world. Therefore a new approach has been developed by Mercedes Benz and PE Europe which integrates the LCA and dismantling/recycling views into one common software solution. Due to the fact that LCA and design for recycling (DfR) are integrated into one tool using one structural model of the analyzed system it is not necessary anymore to create two models, one for LCA issues and one for DfR issues. In addition to the integration of both views, an interface to the internal documentation system has been realized to import the necessary data into the model. This increases the efficiency of data gathering and handling, as well as modelling of the system and data consistency (Ruhland et al. 2004). Since LCA is used since more than ten years at Mercedes Car Group (Kaniut at al. 1995), a comprehensive database of internal processes and processes from suppliers, e.g. based on the VDA data collection format (Finkbeiner et al. 2003), is available.

Apart from the data, the process integration plays the most important role. The responsibility for improving environmental compatibility was an integral part of the organization of the S-Class development project. The management of the overall project appointed people to be in charge of development, production, procurement, sale and other functions. Corresponding to the most important subassemblies and functions of a car, there are development teams (bodyshell, drive system, interior equipment, etc.) and teams with cross-sectional functions (quality management, project management, etc.). One of the cross-sectional teams was the so-called DfE-team. It is made up of experts from the fields of life cycle assessment, dismantling and recycling planning, materials and process engineering, as well as design, sales and vehicle production. This guarantees complete integration of the DfE process in the vehicle development project. The members' duties consist in defining objectives for individual vehicle modules from an environmental angle, checking on their accomplishment and, if necessary, initiating improvement measures.

For the LCA work, this implies two main applications: LCAs for the complete vehicle at the main development milestones and several LCAs for parts to support the choice between different concepts. The complete vehicle LCAs serve mainly as a yardstick, whether the overall target of improvement compared to the previous model is achieved. Therefore, a first complete vehicle LCA is calculated at an early stage of development which is then further detailed and updated at the main development milestones. LCAs for parts are mainly used to support decisions between different technological or material concepts. The LCA results are fed into the product development teams for the different parts of the vehicle. The LCA results and the overall environmental performance is one among several other criteria like technical performance, design, vehicle production, cost, quality, etc. During the S-Class development, LCAs on the part level were calculated e.g. to choose between different body-in-white concepts (different shares of steel, aluminium, plastics) or to choose between different underbody sealing concepts (panels of different plastics).

The integration of DfE in the process organization of the S-Class development project ensured that no hunt for environmental aspects would begin at market launch time. Instead, these aspects were taken into account in the earliest stage of development. Pertinent objectives were coordinated in good time and reviewed at the quality gates in the development process. From the interim results, the need for further action up to the next quality gate was determined and implemented by collaborating in the development teams.

Together with the S-Class project management, the DfE-team had defined the following concrete environmental objectives (Mercedes-Benz 2005):

1. Assurance of compliance with the European ELV directive (ELV 2000). This involves:
   a) Developing a recycling concept to observe the 95 percent by weight recovery rate stipulated by the law for the year 2015.
   b) Assuring observance of prohibited substances in compliance with the European ELV directive.
   c) Optimizing of product concepts for the purpose of recycling-compliant design in order to reduce the resultant cost of recycling.

2. Assurance of the use of recycled plastics in ten percent of the plastics.
3. Assurance of the use of 23 kilograms (component weight) of renewable raw materials.
4. Recording of all substantial environmental burdens caused by the S-Class during its lifecycle by LCA.

The process carried out for the S-Class meets all criteria described in international standard ISO 14062 for the inclusion of environmental aspects in product development.

2 Life Cycle Assessment of the S-Class Vehicle

The environmental compatibility of a vehicle is determined by the environmental burden caused by emissions and the consumption of resources throughout the vehicle lifecycle. The following sections document the goal and scope definition (section 3.1) and the results of the S-Class LCA (section 2.2).

2.1 Goal and scope definition

The main elements of the chosen goal and scope for the S-Class LCA are documented in **Table 1**.

Table 1: Goal and scope definition

Goal Definition	
Project goal	• Life cycle assessment of new S-Class, ECE basic variant S 350 compared to predecessor. ECE relates to a variant type approved according to the United Nations Economic Commission for Europe rules. • Verification of attainment of objective 'environmental compatibility' and communication.
Scope Definition	
Functional unit	• S-Class car (basic variant; DIN weight, driving distance 300.000 km)
Comparability technology/ Product	• As two generations of one vehicle type, the products generally are comparable. Owing to progressive development and changed market requirements, the new S-Class provides additional functions and features, mainly in the area of passive and active safety and in terms of higher performance. If the additions have an influence on the results, this will be commented upon in the course of evaluation.
System boundaries	• Life cycle assessment for car manufacture, use, disposal/ recycling. The system boundaries should only be exceeded by elementary flows (resources, emissions, deposits).
Data base	• Weight data of car: DaimlerChrysler (DC) parts lists (as of 10/2004). • Information on materials for model-relevant, vehicle specific parts: DC parts list, internal DC documentation systems, specialist literature. • Vehicle-specific model parameters (bodyshell, paintwork, catalyst etc.): DC departments. • Location-specific energy supply: DC database. • Information on materials for standard parts: DC database. • Use (consumption, emissions): type approval/certification data. • Use (mileage): definition by DC based on specifications. • Maintenance and care for vehicle have no relevance for the result. • Recycling model: state of the art recycling processes in Europe, the environmental burdens of the recycling/recovery phase are represented based on the standard processes of depollution, drainage, shredder and deposition and/or incineration of the shredder light fraction. Credits are not granted. • Material production, supplied energy, manufacturing processes and transport: Life cycle assessment database (GaBi 4.0); DC database.
Allocations	• Life cycle assessment data (GaBi 4.0) for material production, supplied energy, manufacturing processes and transport are described in the pertinent documentation (http://www. pe-product.de/GABI/Documentation/start_e.HTML). • DC power plant model Sindelfingen is allocated according to exergy (=working portion of generated energy sources electricity and heat). • No further specific allocations.
Cutoff criteria	• Life cycle assessment data (GaBi 4.0) for material production, supplied energy, manufacturing processes and transport are described in the pertinent documentation (http://www.pe-product.de/GABI/Documentation/start_e.HTML). • No explicit cutoff criteria. All available weight information is processed. • Noise and land use are not available as LCA inventory data today and therefore are neglected. • 'Fine dust' and particulate emissions are not analyzed for the gasoline variants. Major sources of fine dust (mainly tire and brake abrasion) are not dependent on vehicle type and consequently of no relevance to the result of vehicle comparison.
Parameters	• Material composition according to the standard VDA 231-106 (VDA 1997). • LCI level: resource consumption as total and non-renewable primary energy, emissions CO_2, CO, NO_X, SO_2, NMVOC, CH_4. These examples are specifically analysed from an LCI perspective, but do not represent the total list of the elementary flows considered. • Impact assessment: Abiotic depletion potential (ADP), global warming potential (GWP), photochemical ozone creation potential (POCP), eutrophication potential (EP), acidification potential (AP). • These impact assessment parameters are based on internationally accepted methods. They are modelled on categories selected by the European automotive industry, with the participation of numerous stakeholders, in an EU project, LIRECAR (Schmidt et al. 2004). • Interpretation: sensitivity analyses of car module structure; dominance analysis over lifecycle.
Software	• DC DfE-Tool. This tool models a car with its typical structure and typical components, including their manufacture, and is adapted with vehicle-specific data on materials and weights. It is based on the LCA software GaBi 4.0.
Evaluation	• Analysis of lifecycle results according to phases (dominance). The manufacturing phase is evaluated based on the underlying car module structure. Contributions of relevance to the results will be discussed.
Documentation	• Final report with all parameters.

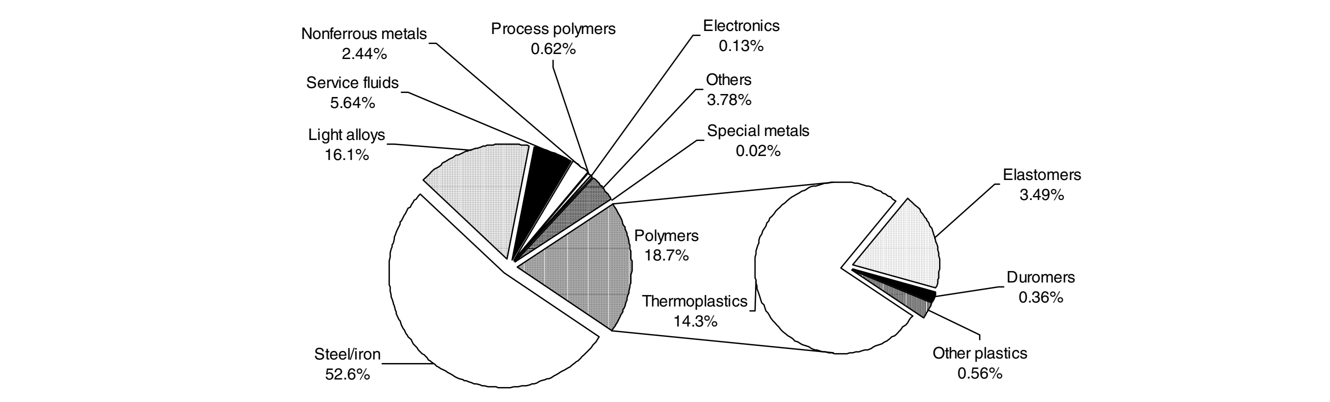

Fig. 1: Material composition of the new S-Class

The weight and material data for the basic variant S 350 was determined on the basis of the internal documentation of the components used in the vehicle (parts list, drawings) and verified by a dismantling analysis. The resulting material composition of the new S-Class (1805 kilograms DIN weight, i.e no driver and luggage, fuel tank 90 percent full) is shown in **Fig. 1**.

Some main parameters for the modelling of the use phase are shown in **Table 2**.

Table 2: Use phase data for new S-Class and predecessor, ECE basic variant with standard tires

Parameter	S 350 new model	S 350 previous model	EU4 [1]	Unit
Power	200	180	–	kW
Fuel consumption NEDC [2]	10.1	11.1	–	l/100km
Carbon dioxide	242	266	–	g/km
Carbon monoxide	0.21	0.185	1.0	g/km
Hydrocarbons	0.026	0.05	0.1	g/km
Nitrogen oxides	0.011	0.046	0.08	g/km

[1] EU4 emission standard (EU 1998)
[2] New European Driving Cycle (EU 1998)

2.2 Results

Some exemplary results of the S-Class LCA are the relevance of the life cycle stages (see section 2.2.1), the comparison with the previous model (see section 2.2.2), the relevance of the different vehicle modules (see section 2.2.3) and an overview of parts made from secondary or renewable raw materials (see 2.2.4).

2.2.1 Relevance of the life cycle stages

Over the entire life cycle of the new S-Class, the lifecycle inventory calculations indicate, for example, a primary energy consumption of 1360 GJ (equal to the energy content of about 32 tons of premium grade gasoline) and emissions to the environment of just under 95 tons of carbon dioxide (CO_2), about 199 kilograms of non-methane hydrocarbons (NMVOC), about 73 kilograms of nitrogen oxides (NO_X) and around 70 kilograms of sulfur dioxide (SO_2). In addition to the analysis of overall results, the distribution of single environmental impacts among the different stages of the life cycle is investigated. The relevance of each life cycle stage depends on the particular environmental impact being considered. For CO_2 emissions and also primary energy consumption, the use phase dominates with a share of over 85 percent (**Fig. 2**). However, it is not the use of the vehicle alone which determines its environmental compatibility. Some environmentally relevant emissions are caused principally by its manufacture, for example the SO_2, CH_4 and NO_X emissions (see Fig. 2). The manufacturing phase must be included in the analysis of ecological compatibility for this reason. For many emissions today, the dominant factor is not so much the automotive operation itself, but the production of the fuel, for instance for hydrocarbon (NMVOC) and NO_x emissions and for the environmental impacts which they essentially entail: photochemical ozone creation potential (POCP) and acidification potential (AP).

In addition to those given in Fig. 2, there were many other parameters analysed and respective results obtained. These include for example, that municipal waste and tailings (particularly ore dressing residues and overburden) originate mainly in the manufacturing phase, whereas the hazardous wastes mainly are caused by the provision of gasoline during the use phase. Burdens on the environment due to emis-

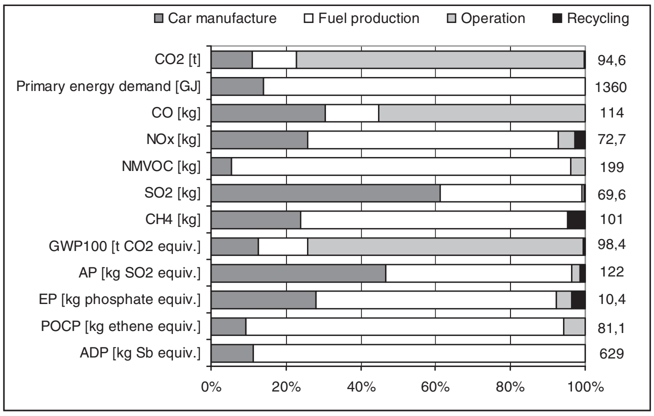

Fig. 2: Share of lifecycle stages in selected parameters of the new S-Class

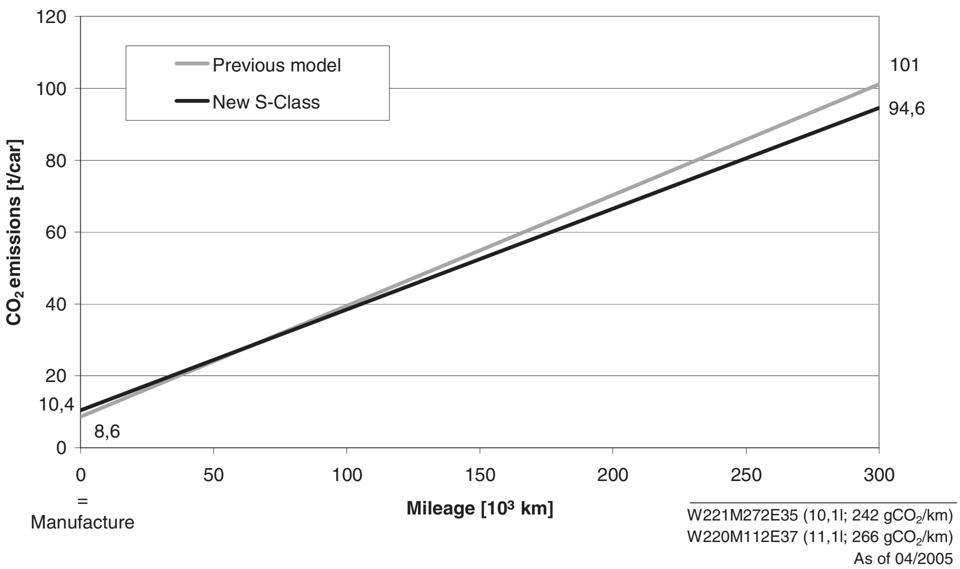

Fig. 3: Comparison of carbon dioxide emissions, new S-Class vs. previous model

sions in water are mainly a result of vehicle manufacture, in particular owing to the output of heavy metals, NO_3^- and SO_4^{2-} ions as well as the factors AOX, BOD and COD.

2.2.2 Comparison with the previous model

Parallel to the investigation of the new S-Class, an LCA was conducted for the previous model in its ECE basic variant (1735 kilograms DIN weight). The parameters on which this was based correspond to those described earlier for the new model: manufacture was modelled on the basis of a current parts list excerpt. The use of the comparably engined predecessor was calculated with current certification data (see also Table 2). For recycling/recovery the same state-of-the-art model was taken as basis.

The additional weight of the new model compared to the predecessor (ECE basic variant in each case) necessarily causes a larger burden on the environment in production. The main reasons are higher requirements for safety equipment and the increased demand for comfort-affording components. The light alloy share is 3.3 percent higher; in production, light alloys give rise to bigger environmental burdens than, for example, steel. Due to the increased weight and the changed composition of the materials, the new model gives rise to higher environmental burdens in production; the primary energy requirement for this phase is just about 20 percent higher than the predecessor's.

Comparing the whole life cycles, however, the new model has a smaller primary energy demand. The disadvantages in vehicle manufacture (additional expenditure 31 GJ/car) are more than offset by the lower fuel consumption (savings of 116 GJ/car). At about 85,000 km both cars are about level, but by the end of its use the new S-Class consumes 85 GJ less than its predecessor. This is equivalent to the energy content of about 2,500 litres of gasoline. For the carbon dioxide emissions the new model attains a comparable advantage over its life cycle; here the breakeven point already is reached at 65,000 km (**Fig. 3**).

Resource consumption is specified by the impact category ADP (abiotic depletion potential). This category indicates the changes in detail: due to the more extensive use of materials, more material resources (mainly bauxite, copper ore and dolomite) are consumed in the manufacture of the new S-Class. The consumption of energy sources (brown and hard coal and uranium) employed in processing the materials also rises. This compares with the input of less fuel during use. The crude oil saved in use outweighs the increase in resource consumption during manufacture. Over the entire life cycle the abiotic depletion potential is reduced by seven percent. Other results of category indicators reveal e.g. a reduction in eutrophication potential (EP) of 13% [kg Phosphate-Equiv.] and a reduction in photochemical oxidant creation potential (POCP) of 9% [kg Ethene-Equiv.].

2.2.3 Relevance of the different vehicle modules

In addition to analyzing overall results, the distribution of selected environmental impacts among the manufacture of single modules is studied. Exemplarily, **Fig. 4** shows the carbon dioxide and sulfur dioxide emissions. Whereas the body shell dominates in the area of carbon dioxide emissions, the electrics/electronics, engine and exhaust system are found to be more relevant for the sulfur dioxide emissions. This is mainly due to the use of precious and nonferrous metals, which give rise to high sulfur dioxide emissions in the production of the material.

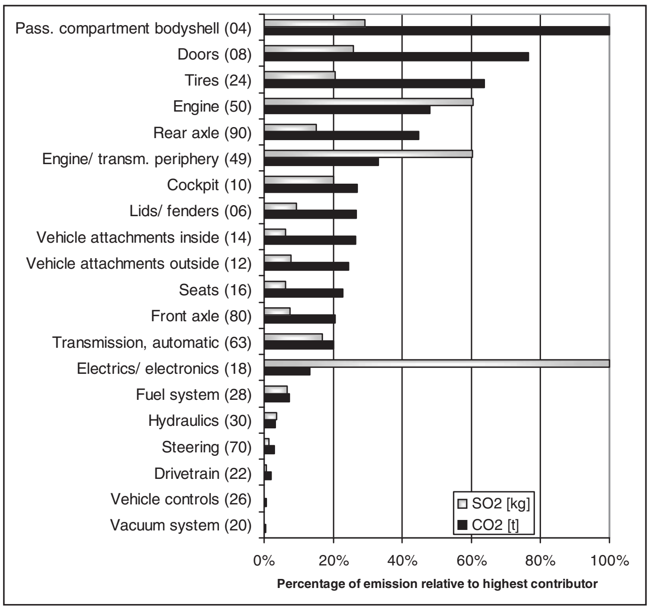

Fig. 4: Share of main component groups in selected LCI parameters of the new S-Class

Fig. 5: Components of the new S-Class approved for recycled plastics

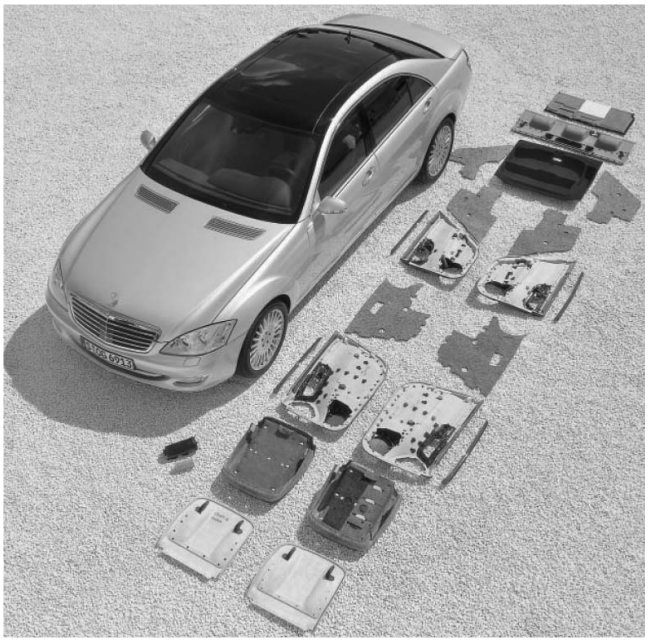

Fig. 6: Components of the new S-Class made of renewable raw materials

2.2.4 Parts made from secondary or renewable raw materials

The investigations on the use of secondary raw materials which accompany development focus on the thermoplastic plastics. In contrast to e.g., steel and iron, whose primary material already has a percentage of secondary raw materials included in it, for plastics applications it is necessary to perform separate testing and approval of the recycled material for each particular component. The demands on the component in respect of quality and functionality must be equally met with the secondary raw materials as for a comparable virgin material. From a life cycle perspective, secondary materials very often offer the potential for improved environmental performance. However, it is the role of LCA to double-check for the individual parts, if this potential is realised or if there is a case, where the environmental burden is larger than for the primary material.

In the new S-Class, a total of 45 parts with a total weight of 21.2 kilograms can be manufactured using a percentage of high grade recycled plastics. This increased the mass of approved components made of secondary raw materials versus the previous model. The potential for the use of recycled plastics is limited to applications in non-visible areas and already is exhausted for the most part today. Typical applications are wheel arch linings, cable ducts, under body panelling, which mostly consist of the plastic polypropylene.

A further objective is to obtain the secondary raw materials from vehicle-related waste flows if at all possible, in order to close the cycles. For instance, for the front wheel arch linings of the new S-Class a secondary raw material is used which is made up of reprocessed vehicle components: cases of starter batteries, bumper coverings from the Mercedes-Benz Recycling System and production wastes from cockpit manufacture. **Fig. 5** shows the components for which the use of secondary raw materials is approved.

In automobile manufacture, the use of renewable raw materials concentrates on applications in the interior. Natural fibres used in the production of the new S-Class are coconut, wood, flax and cotton fibre in combination with different polymers. In the new S-Class a total of 27 parts with a total weight of just about 43 kg are manufactured using natural materials. With that, the total weight of the components manufactured using renewable raw materials has increased by some 73 percent versus the previous model. **Fig. 6** shows the components of the new S-Class made of renewable raw materials. Again, LCAs for the different fibres and their alternatives are used to identify the respective environmental advantages and disadvantages and to develop environmen-

tal recommendations for individual parts. For the S-Class, the new components were analysed and showed advantages from an overall LCA-perspective.

3 Discussion and Conclusion

To be confident with measures to improve the environmental performance of products requires the system perspective. Therefore, Life Cycle Assessment and Life Cycle Engineering are valuable tools to achieve this goal.

Vehicles are complex products with very complex interactions with the environment. Therefore, simple solutions, e.g. pure focus on fuel economy or light weighting or recycling or single material strategies, are bound to fail. It is a main task of DfE and LCA to take this fact into account and come up with more intelligent solutions. To make the results and recommendations based on LCA relevant, it is necessary to implement LCA into the product development process. At the Mercedes Car Group of DaimlerChrysler LCA is used as tool for Design-for-Environment. The application of LCA for DfE and their integration as standard practice in the product development process is both the most demanding and the most rewarding. It requires a substantial effort to acquire the know-how, the data, the experience and the tools needed to generate meaningful results just in time. However, this is the way how LCA and DfE can add value – they have to be 'built' into the product.

The process of integrating environmental aspects in product development is only effective if it leads to an improved product. Actual environmental improvements achieved on the product are the 'real' benchmark of whether the DfE process is successful. As far as the new S-Class is concerned, the LCA confirmed an 85 giga joules reduction in overall energy demand compared to the preceding model, corresponding to the energy content of approximately 2,500 liters of fuel. Over the life cycle, emissions of the carbon dioxide greenhouse gas have been reduced by 7%, with a 14% reduction in nitrogen oxide emissions compared to the previous S-Class. A total of 45 components with an overall weight of around 21 kilograms are made from high quality recycled plastics. This represents a 4% increase in the weight of approved recycled components compared with the previous model. In addition, 27 components with a combined weight of around 43 kilograms are made from natural materials. Compared to the preceding model series, this is an increase of approximately 73% in the total weight of components made from renewable raw materials.

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